Financial Costs and Benefits of Reduced-Impact Logging Relative to Conventional Logging in the Eastern Amazon

Thomas P. Holmes[1], Geoffrey M. Blate[2], Johan C. Zweede[3], Rodrigo Pereira, Jr.[3], Paulo Barreto[4], Frederick Boltz[5] and Roberto Bauch[6]

[1] Southern Research Station
USDA Forest Service
PO Box 12254
Research Triangle Park, NC 27709

[2] Tropical Forest Foundation
225 Reinekers Lane, Suite 770
Alexandria, VA 22314

[3] Fundação Floresta Tropical
Belém, Pará
Brazil

[4] Instituto do Homen e Meio Ambiente da Amaz⊥nia
Belém, Pará
Brazil

[5] School of Forest Resources and Conservation
University of Florida
Gainesville, FL 32611

[6] Consultant
Svo Paulo
Brazil

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EXECUTIVE SUMMARY

This report provides a comparison of the costs and revenues of a typical Reduced Impact Logging (RIL) system relative to a typical, large-scale Conventional Logging (CL) system in the eastern Amazon. The analysis focuses on financial, operational, and technical aspects of CL in relation to RIL techniques and procedures. Although the study does not address biological or ecological questions directly, measurements were made of two key parameters affecting future forest productivity: damage to trees in the residual stand and the proportion of ground area disturbed.

An economic engineering approach was used to estimate standardized productivity and cost parameters for typical RIL and CL operations in the Paragominas, Par< timbershed. Detailed data on productivity, harvest volume, wasted wood and damage were collected from on-site harvest blocks. Productivity and cost data were also collected using surveys of forest products firms in the timbershed.

The major conclusion of the study was that reduced impact logging can be financially more profitable than conventional logging. This implies that economic self interest can help mitigate the loss of ecological services in tropical forests subject to logging pressure. However, a word of caution is due. Because tropical forests are heterogeneous and the markets for production inputs and outputs are variable, the conclusions of this study do not necessarily apply to other timbersheds in the Amazon basin or elsewhere. It is imperative for future studies to identify the set of conditions under which RIL can compete financially with conventional logging practices.

Investments in “human capital”, or training forest workers, yielded financial dividends in the initial harvest in terms of more efficient use of machinery (human-made capital) and timber (natural capital). Efficiency gains to skidding and log deck productivity were large, but required investments in planning that would nearly triple conventional logging fixed costs. Better recovery of potential merchantable timber volume using RIL techniques reduced the direct and indirect costs associated with wasted wood and increased the volume of wood that could be recovered from a fixed resource base. Overall, the cost per cubic meter associated with a typical RIL system in this timbershed was 12% less than the cost of a typical CL system.

Reduced impact logging techniques greatly reduced damage to trees in the residual stand and reduced the amount of ground area disturbed by machinery. This result implies that future economic and ecological benefits provided by logged forests will be greater where RIL techniques are used.

Adoption of RIL methods are likely hindered by a number of factors, including: (1) the perception that RIL systems are more expensive than CL systems, (2) failure of CL cost accounting systems to recognize direct and indirect costs associated with wasted wood, (3) the lack of trained human resources for field implementation, (4) high net profit margins, inducing maximization of “throughput” rather than profit, (5) adjustment costs related to machine replacement and the opportunity cost of worker training may be nonzero, (6) standing timber prices may be undervalued, and (7) environmental regulations are not fully enforced.

Contents

1. Introduction

Rain forest logging, as conventionally practiced in the tropics, depletes timber stocks and causes severe ecological impacts on residual forests that are not accounted for in economic terms (Repetto and Gillis 1988; Johnson and Cabarle 1993). Ecological degradation of logged forests induces economic costs due to loss of ecological services such as watershed protection, carbon sequestration, harvest of non-timber forest products and conservation of biological diversity (Dixon and Sherman 1990; Chomitz and Kumari 1998). Although the economic benefits of protecting and conserving tropical forests are probably large, quantification of these benefits is rarely undertaken (Albers, Fisher and Hanemann 1996; Kramer and Mercer 1997). Economic cost-benefit analysis may ultimately justify the institution of financial incentives or imposing regulations on the forest products industry to adopt sustainable management practices. However, funding mechanisms for financial incentive programs are uncertain and existing forestry regulations are often not fully enforced. Consequently, an alternative strategy to promoting good forestry practices in the tropics is to evaluate under what conditions the financial profitability of firms can be increased by adopting best forestry practices (Putz, Dykstra and Heinrich 1999). That is, can economic self interest help mitigate the loss of ecological services in tropical forests subject to logging?

Conventional timber harvesting systems do not utilize best harvesting practices.

Reduced impact logging (RIL) systems are currently being developed in Brazil and other countries with tropical forests in response to domestic and international concern over the ecological and economic sustainability of harvesting natural tropical forest stands. RIL systems use an array of best harvesting techniques that reduce damage to the residual forest, reduce soil disturbance and soil erosion, protect water quality, mitigate fire risk and potentially help maintain regeneration and protect biological diversity. The FAO model code of forest harvesting provides the basis for RIL system design and typically includes many or all of the following activities (Dykstra and Heinrich 1996): pre-harvest inventory and mapping of trees; pre-harvest planning of roads and skidtrails; pre-harvest vine cutting (where necessary); directional felling; low stumps; efficient utilization of felled trunks; optimum width of roads and skid trails; winching of logs to planned skid trails; optimal size of landings; minimal ground disturbance and slash management. RIL techniques and guidelines are not fixed prescriptions, but adapt best harvesting techniques to existing biophysical and economic conditions.

RIL systems rely on investment in "human capital" to train and develop forest workers who understand and are committed to the application of best harvesting practices. Improvements in human capital can benefit logging operations by reducing costs associated with wasted wood and reduce machine time by improving the efficiency of machine movement. Forest workers trained in RIL techniques also operate more safely than workers receiving traditional on-the-job training. Training aimed at providing professional status for forest workers has been shown to reduce injury rates and, consequently, reduce the costs associated with workers' compensation (Jenkins and Smith 1999).

The ecological benefits of RIL relative to conventional logging (CL) practices have been verified using ecological measures such as reduced damage to soils and the residual stand, improved regeneration rates and improved nutrient conservation (e.g., Boxman et al. 1985, Jonkers and Hendrison 1987; Johns et al. 1996). However, little is known about the financial aspects of RIL, and existing evidence in Latin America is inconclusive. While it is premature to make a definitive statement, existing data suggest that RIL systems can be more profitable than CL systems under some conditions. Defining the set of conditions that favor the financial aspects of RIL deserves significant research effort. If a "feasible financial set" is identified by subsequent research, then economic self-interest may help protect ecological services in some logged tropical forests. Other institutional mechanisms will need to be developed where the financial profitability of RIL can not be counted on to stimulate the adoption of best harvesting practices.

Development and application of the CELOS system in Suriname showed that planned logging could be cheaper than conventional logging due to reduced skidding costs (Hendrison 1990). Recent research in the eastern Amazon state of Pará, using a modification of the CELOS system developed by IMAZON, confirmed this result and showed that RIL increased profitability relative to conventional logging (Barreto et al. 1998). However, another study in Brazil, near Manaus in the state of Amazonas, found that environmentally sound forest harvesting was moderately more expensive than the traditional logging system (Winkler 1997). This may have been due to a modified skidding system which utilized both pre-skidding and skidding phases. In Guyana, recent research showed that the cost of RIL was nearly identical to the cost of "traditional" logging, although the "traditional" operation in that study utilized moderate planning and was considerably more sophisticated than "hit and miss" logging utilized as CL comparisons in the Brazil studies (van der Hout 1999). Finally, a recent study in Ecuador reported that the cost of RIL was moderately higher than the cost of CL (Montenegro 1996). It should be noted that, in both the Amazonas study and the Ecuador study, the logging intensity was much higher on the CL sites. This difference would have the effect of lowering the per unit cost and favoring the CL operation.

In addition to financial impacts, RIL systems can provide other industrial benefits. RIL procedures reduce the volume of timber wasted in harvesting operations, thereby increasing the volume of timber supplied from a fixed resource base (Pulkki 1998). Pre-harvest inventories of standing timber provide a marketing advantage to landowners and mills who can establish forward contracts with buyers based on delivery of known volumes for specific species. Inventory control also helps eliminate low prices and degrade associated with products that sit in mill yards because buyers cannot be found. Careful tree felling and machine use using RIL techniques increases worker safety which should result in lower insurance rates and a more secure workforce. RIL systems are also an integral part of forest certification initiatives (Putz and Viana 1996; de Camino and Alfaro 1998) and may provide a low cost method of achieving carbon sequestration targets (Putz and Pinard 1993; Boscolo, Buongiorno and Panayotou 1997) and forest conservation benefits (Frumhoff and Losos 1998).

The analysis presented in this report provides a comparison of the costs and revenues of a typical RIL system relative to a typical, large scale CL system in the eastern Amazon. The study focuses on the financial, operational, and technical aspects of CL vs. RIL systems. Although the study does not address biological or ecological questions directly, measurements were made of key parameters affecting future forest productivity and these parameters represent future benefits of using RIL systems. In the future, we intend to investigate how RIL methods must be modified to be cost effective in other settings characterized by variation in forest type, markets for inputs and outputs and size of operation.

2. Study Setting

In the Brazilian Amazon, between 8,000 and 15,00 km^2 are annually logged, mostly using CL practices (Holdsworth and Uhl 1997; Nepstad et al. 1999). In the eastern Amazon state of Par<, loggers harvest 4-8 trees/ha (Johns et al. 1996; Holdsworth and Uhl 1997; Uhl et al. 1997), reduce canopy cover by 50% or more (Uhl and Viera 1989), severely disturb mineral soils (Johns et al. 1996) and kill or damage 10-40% of the living biomass (Verissimo et al. 1992). The resulting mosaic of gaps and forest patches is especially fire prone due to increased light penetration and fuel load (Holdsworth and Uhl 1997; Cochrane and Schulze 1999; Nepstad et al. 1999). If forestry is to hold promise as a sustainable conservation and development option, ecological impacts of timber harvesting need to be mitigated using technology that is economically competitive with current destructive practices.

Attitudes in Brazilian society are changing from viewing forests as a development impediment to viewing forests as a renewable resource to be managed.[1] With this change in perspective, the demand for information regarding sustainable forest management has grown. Because timber harvesting has the greatest ecological impact of any forest management activity, RIL methods are a necessary component in the design of sustainable timber management systems.

For the past several years, the Tropical Forest Foundation (TFF) and its Brazilian subsidiary Fundação Floresta Tropical (FFT) have developed and implemented operational RIL models at various locations throughout the Brazilian Amazon and trained forestry personnel in RIL methods. To date, FFT has established 5 RIL forest management models in four forestry regions of the Amazon: (1) Cauaxi, Pará, (2) Portel, Pará, (3) Marcelândia, Mato Grosso, (4) Claudia, Mato Grosso, and (5) Tapajós National Forest, Pará. Each region represents a different forest type and faces a different market for wood products.

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[1]There has been a significant increase in the application of environmental regulations in the Brazilian Amazon. Resources for enforcement of environmental legislation in the Amazon have increased from R$0.5 million in 1994 to R$1.8 million in 1997 and the number of fines for “environmental resources” has increased from 5,278 in 1994 to 10,717 in 1997. Ninety percent of these fines are related to crimes against the flora (deforestation, illegal logging and illegal transport of wood). The value of fines collected has increased from R$2.5 million in 1994 to R$6.9 million in 1997 (Hirakuri and Barreto *in prep*).

2.1 Site description

Between 1995 and 1997, FFT established several 100 ha cutting blocks at Fazenda Cauaxi. Cauaxi is situated about 120 km southwest of Paragominas ($3^o35'$ - $3^o45'$ S; $48^o15'$ - $48^o25'$ W) on moderately undulating terrain formed from the residual tertiary plateau. The soils are oxisols with a distinct argillic horizon. Annual rainfall averages 2200 mm with a distinct dry season from June to November. Mean annual temperature is 28^o C. The forest is classified as tropical moist (Walsh 1996). It is a mixed forest with more than 124 species (dbh > 10 cm) and patches of emergent trees exceeding 50 m in height (top of crown). The vine load is considered dense.

FFT established Block 1 as a conventional logging block, Blocks 2, 3, 4 and 6 as RIL blocks, and Block 5 as an unharvested control (see Cauaxi Block Layout at end of report). FFT conducted 100% pre-harvest inventories of commercial and potentially commercial trees on all blocks and established permanent plots representing 1% of the area in each of the blocks.[2] Pre-harvest inventories included all commercial and potentially commercial trees greater than or equal to 35 cm d.b.h. on blocks 1 (CL) and 3 (RIL). Post-harvest inventories were also conducted on blocks 1 and 3 to allow computation of waste and damage.

Roads cause land use changes by providing market access for agricultural and forestry products.

[2] The area in permanent plots represented in each block is two times greater than required by Brazilian law.

2.2 Market setting

The establishment of the Belém-Brasilia highway opened the forest frontier in Paragominas to harvesting and wood processing activities in the early 1970's. During the 1970's and 1980's the industry grew rapidly as many firms entered the market (Verissimo et al. 1992). Much of the industry growth during this period was due to agricultural subsidies that induced conversion of forests to pasture and provided low-cost wood. During the 1990's entry into the industry slowed, exit of firms increased, better capitalized firms expanded processing capacity to capture economies of scale and some firms established export clearing houses that dry, plane and package wood for the export market (Stone 1996).

As the wood products industry matured, standing timber became more scarce. Log hauling distances increased, and firms began using larger trucks to help control transportation costs. Between 1990 and 1995, delivered log prices in the Paragominas timbershed increased by 10-30% and stumpage prices doubled (Stone 1996). Whether or not stumpage price increases will be sufficient to induce forest conservation and management activities in the Paragominas timbershed remains to be seen.

Most wood processed by mills in Paragominas is marketed domestically. Access to domestic markets permits 40 - 50 tree species to be harvested in this location. Northeast Brazil is the primary market for wood harvested in this timbershed (43% of volume), followed by the southeast (39%), the south (8%), other areas in Brazil (2%). About 8% of the wood processed in Paragominas is for the export market (Ferreira 1996).

In the Paragominas timbershed, CL operations can be categorized into three *terra firme* logging classes. The smallest CL operations (Class I) typically use a farm tractor and truck for logging. This scale of operation has the least impact on the residual forest. The second class (Class II) of CL operations is intensive, highly destructive and provides the initial step in converting forest to pasture. These operators typically own a small mill and some forest land, but rely on timber supplied from non-industrial private forests. They are the most common in terms of number of operators and volume of timber harvested. The third class (Class III) of CL operations are large, industrial landowners, often with vertically integrated operations, who supply their mills predominately with timber harvested from their own land. These operations typically use the most modern equipment but, because of harvesting techniques used, have a large impact on the residual stand.

3. Methods

An assessment of the financial feasibility of RIL is complicated by the fact that tropical forests are heterogeneous. Variation in stocking of commercial timber species and harvest design parameters (e.g., crew size, inventory intensity, skidding technique) affect productivity and cost. In order to mitigate some of the limitations associated with conducting a case study, we utilized an economic engineering approach to estimate productivity and cost parameters (Hyde 1980). "Typical firm" parameters were estimated for large-scale (Class III) RIL and CL operations in the Paragominas timbershed using technical, engineering and economic data representing multiple sites.

3.1 Data sources

Average timber harvesting costs decrease, up to some point, with an increase in harvest intensity. To help mitigate potential for a biased comparison due to unequal harvest intensity on RIL and CL blocks, a standard harvest volume (q_{std}) was computed as the average harvest volume from Cauaxi blocks 1 (conventional block), 3 and 4 (reduced impact blocks). It was found that q_{std} = 25.36m^3/ha.[3]

Standardized productivity parameters for the RIL account were estimated by computing average values using data collected on several harvest blocks at Cauaxi and other comparable FFT model sites.[4] Standardized activity costs were estimated using hourly costs for labor and capital inputs. Hourly labor costs were based on the standard monthly wage for each job category and the average number of effective work hours per month.[5] Fixed equipment costs (depreciation, interest, insurance and taxes) were amortized on an hourly basis.[6]

Productivity and cost of CL harvesting activities were estimated from survey data collected from CL operators in the Paragominas timbershed. Data included information on timber harvesting productivity, labor cost, equipment used, crew composition and timber defects accepted by mills (FFT 1998; Paulo Barreto, *unpublished data*). Productivity and cost parameters were estimated by averaging across the surveyed firms.

For the CL account, the list of materials used included only safety items required by law. For the RIL account, the list of materials used included safety items required by law as well as additional items deemed necessary for personnel safety and health.[7]

In contrast to productivity and cost parameters, inventory, damage and waste parameters were not averages but were computed using data collected on RIL block 3 and CL block 1 at Cauaxi. Damage and waste parameters were computed based on a census of each 100 hectare block.

To allow estimation of net revenues and profit margins for typical RIL and CL operations, revenue data were collected. Gross revenue per m^3 at the forest log deck was computed using log prices for three value classes: *branco* (low value) = \$10.74/m^3, *vermelho* (medium value) = \$21.61/m^3 and *nobre* (high value) = \$58.57/m^3 (C. A. P. Ferreira, *pers. comm.*). A weighted average price (\$25.50/m^3) was computed using the volumes recovered on Cauaxi blocks 1 and 3 in each value class.

The analysis was based on actual 1996 values for factor costs and output prices. Values were reported in 1996 US dollars.

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[3] This amount is similar to the average harvest intensity for firms in this timbershed as reported in an industry survey conducted by FFT (1998).
[4] See Appendix 3: Productivity Worksheet for specific details.
[5] See Appendix 5: Calculation of Hourly Costs Based on Monthly Base Salaries.
[6] See Appendices 6b through 6g. For CL operations, amortization schedules may result in conservative capital cost estimates because maintenance schedules may not be followed and equipment may receive rougher than average treatment.
[7] See Appendix 6a for a list of materials used by CL and RIL operations.

3.2 Harvesting systems

Timber harvesting on RIL blocks at Cauaxi were designed to be efficient, but not necessarily least-cost. Harvesting activities were planned up to 8 months in advance and crews were trained in RIL methods. A full inventory of commercial and potentially commercial trees greater than 35cm dbh occurred 7 months in advance of harvest and vines were cut at that time. A crawler tractor (Caterpillar D6 SR) was used for construction of roads and log decks and a rubber tire skidder (Caterpillar 525) with winch and grapple was used for skidding operations. Skid trails were laid out, but not constructed, in advance. Trees were directionally felled and sawyers used a Stihl AV 51 chainsaw for felling and bucking operations. Logs were sorted and loaded on the log deck with a Caterpillar 938F Loader. Roads, log decks and principal skid trails were constructed to be part of the permanent infrastructure to be available for the next harvest.

Directional felling is a key step in reducing damage to the residual stand and increasing logger safety.

An industrial cooperator performed the timber harvest on the CL block. Harvesting crews had received on-the-job-training but had not received training in RIL methods. The CL operator used a crawler tractor (Caterpillar D6 Logger) with winch for constructing roads and log decks and for skidding operations. A “tree hunter” (*mateiro*) worked with the sawyer in a “hit or miss” search for merchantable trees. Directional felling techniques were not used. Sawyers used a Stihl AV 51 chainsaw for felling and bucking operations. Timber fellers were paid on a piece rate that encouraged rapid felling with little regard for impacts on the residual stand. Skidding crews were not provided with precise information from felling crews regarding location of felled trees and therefore needed to search for logs. This resulted in an inefficient skidding operation with significant damage to the residual stand, forest soils and skidding equipment. Logs were sorted and loaded using a Caterpillar 938F Loader.

3.3 Timber waste

The volume of merchantable timber wasted in RIL and CL blocks was computed using a census of each 100 ha harvesting block (blocks 1 and 3).[8] Timber was wasted both in the forest and on the log deck. Three categories of timber wasted in the forest were measured: (1) timber wasted by cutting stumps too high, (2) timber wasted in the stem or crown (e.g., merchantable branches) of harvested trees due to improper bucking practices, and (3) timber wasted because logs were not found by the skidder or bulldozer operator. The formula used for computing the volume of wasted wood (*waste_vol*) was:

(1) $$waste\_vol = \frac{\pi d^2 h}{4}$$

where d is diameter and h is height.

In the CL operation, logs were left on the log deck and never transported to the mill due to improper selection of size, species or defect. Computations of volume left on log decks were made using the same method used for calculating the volume of wood left in the forest.[9]

3.4 Harvesting costs

The economic engineering method was used to estimate productivity and cost parameters for each component activity of the timber harvesting system. Cost per cubic meter (*cost/m*^{3}) was estimated as the sum of average fixed cost (f), average variable cost (v), average waste cost (w), average stumpage cost (8), and average training or "human capital" cost (h):

(2) $$\cos t / m^3 = f + v + w + \lambda + h.$$

3.4.1 Fixed cost

Fixed costs were partitioned into the following stages: (1) pre-harvest, (2) harvest planning and (3) infrastructure costs. Specific activities associated with each stage were:

- <u>Pre-harvest</u> **–** Block layout, inventory, vine cutting, data processing, and mapmaking.
- <u>Harvest Planning</u> - Tree marking, road planning and log deck planning.
- <u>Infrastructure</u> - Road construction, log deck construction, and skid trail layout.

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[8] Merchantability was defined as timber sufficiently free from defects such that a typical mill in the region would accept it. Managers of 7 sawmills in Paragominas were interviewed to determine the specifications for acceptable defects (FFT 1998).

[9] For a description of the methods used to measure wood waste, see Appendix 8.

Minimizing the width of forest roads reduces costs and decreases ecological damage.

Fixed cost per cubic meter (f) associated with pre-harvest, harvest planning and infrastructure stages were computed for each activity using the formula:

(3) $$f = \frac{t_l \cdot (c_l + c_m) + t_e \cdot c_e}{q_{std}}$$

where:
t_l = labor time, in hours, required per hectare
t_e = equipment time, in hours, required per hectare
c_l = labor cost per hour[10]
c_m = materials cost per hour
c_e = equipment cost per hour.

Pre-harvest and harvest planning activities typically occur 6 to twelve months prior to harvest. Planning costs were compounded forward at the rate of 27.4 % per annum.[11] Block layout, road planning and log deck planning costs were compounded for 8 months. Inventory, vine cutting, road construction and log deck construction costs were compounded for 7 months. Data processing and mapmaking expenses were compounded for 3 months.

In addition, two other fixed cost categories were included: (1) support (e.g., cook, food, camp, support vehicle), and (2) overhead (e.g., office, administration, communications). Support cost was computed by dividing support cost per harvest season by estimated volume harvested during a season. Support costs were prorated over the total volume harvested during 8 months for RIL operations and 7 months for CL operations.[12] Overhead costs were computed as 10% of average

[10] Hourly costs by activity are shown in Appendix 2.
[11] This was the average nominal interest rate for Brazil in 1996 (Banco Central do Brasil, Relat∴rio Annual 1997).
[12] See Appendix 7 for details of support costs.

variable cost.

3.4.2 Variable cost

Variable costs were computed for harvest activities associated with felling, bucking, skidding and log deck operations. Variable cost per cubic meter associated with harvest stage activities were computed as:

(4)
$$v = \frac{c_l + c_e + c_m}{p}$$

where:
p = harvest productivity, in cubic meters per hour.

3.4.3 Waste adjustment cost

The volume of timber wasted is the difference between the potential volume recovered under "ideal" logging and the actual volume recovered. The potential volume was defined as the actual volume recovered on the standard block (25.36 m^3/ha) plus the volume lost in the following categories: (1) felled logs not found by skidding crew, (2) volume lost because poor felling caused logs to split and lose merchantability, (3) volume lost because logs were left unutilized on the log deck, (4) volume lost due to cutting stumps too high and (5) poor bucking of felled logs. Wasted wood incurs direct costs associated with felling, bucking, skidding and log deck activities (waste categories 1 through 3) and indirect costs by increasing effective stumpage price (waste categories 1 through 5).[13]

Waste factors were computed to account for the total volume of wood felled, bucked and skidded for each unit of wood transported to the mill. The formulas used were:

(5)
$$\alpha = \frac{q_{split}}{q_{std}}; \beta = \frac{q_{lost}}{q_{std}}; \delta = \frac{q_{deck}}{q_{std}}$$

where q_{split} is per hectare timber volume wasted due to splitting, q_{lost} is per hectare timber volume wasted because merchantable felled logs were not found by the skidding crew, and q_{deck} is per hectare timber volume wasted because logs were left unutilized on the log deck. Each ratio indicates the timber volume wasted at each harvesting step as a proportion of the standard volume of wood recovered and transported to the mill.

Waste cost per m^3 (w) was computed by multiplying each waste factor by the appropriate variable cost per cubic meter recovered and then summing:

[13] Barreto et al. (1998) accounted for wasted wood by adjusting gross receipts downward. In contrast, we accounted for wasted wood by adjusting cost upward. This appears to be a more conservative approach.

(6) $$w = \alpha(v_{fell}) + \beta(v_{fell} + v_{buck}) + \delta(v_{fell} + v_{buck} + v_{skid} + v_{deck})$$

where (v_{fell}) is average variable cost of felling trees, (v_{buck}) is average variable cost of bucking logs, (v_{skid}) is average variable cost of skidding logs, and (v_{deck}) is average variable cost of log deck operations.[14]

3.4.4 Stumpage cost

Stumpage costs were computed to account for indirect costs associated with wasted wood on RIL and CL operations. In the study area, stumpage was typically sold as "harvesting rights" on a per hectare basis (8_{ha}).[15] If RIL operations were more efficient than CL in recovering the volume potentially available for harvest on a standard cutting block, then stumpage cost per m^3 of wood recovered would be lower (higher) for the RIL (CL) operation.

Stumpage cost per m^3 on the typical RIL block (8^{ril}) was computed as stumpage cost per hectare divided by the standard volume:

(7) $$\lambda^{ril} = \frac{\lambda_{ha}}{q_{std}}.$$

Stumpage cost per m^3 on the typical CL block included a factor ()) for the difference in total volume of wood wasted (waste categories 1 through 5) between CL and RIL blocks:

(8) $$\Delta = w^{cl} - w^{ril}$$

where w^{cl} is the volume per hectare of timber wasted on the CL block and w^{ril} is the volume per hectare of timber wasted on the RIL block. Stumpage cost per m^3 on the typical CL block was computed as:

(9) $$\lambda^{cl} = \frac{\lambda_{ha}}{q_{std} - \Delta}.$$

3.4.5 Human capital (training) cost

RIL crews received specialized training to increase harvesting efficiency and decrease ecological impacts. CL crews received on-the-job training but did not receive specialized training. Therefore, if CL crews were to adopt RIL methods, investments would need to be made in "human capital". Estimated training costs for RIL were amortized over a 5 year period based on the assumption that crews would need retraining after that period. Amortized training costs were divided by estimated volume harvested over this period to arrive at an average training cost of $\$0.21/m^3$.

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[14] RIL felling costs were not measured independent of bucking. Therefore, it was assumed for this calculation that RIL felling costs were 50% of felling plus bucking costs.

[15] Stone (1996) reported an average stumpage cost of $193/ha for the study area.

Investments in "human capital" yield payoffs in current and future harvests.

3.5 Damage to residual stand

Damages avoided to the residual stand through implementation of RIL methods are benefits of RIL relative to CL systems. In this study, two key parameters indicating severity of damage to future forests were measured: damage to trees in the residual stand and the proportion of ground area disturbed. While it is recognized that reducing damage increases economic and ecological value of future forests, measurement of these values in economic terms was beyond the scope of this study.[16]

3.5.1 Damage to trees

Damage estimates were based on 100% census of Cauaxi blocks 1 and 3 of all commercial and potentially commercial tree species with good form and dbh $\geq$ 35cm. Only trees meeting these criteria were included because they will likely comprise harvests in the second cutting cycle. The census was conducted about 20 months after harvest, so damage due to harvest-gap induced windthrow was included.

Identical protocols were used on RIL and CL blocks and the same FFT technician supervised data collection. Trees were located using an inventory list with coordinates, common and scientific names, tree numbers, and diameters.[17] Two assistants helped locate trees on the list,

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[16] Economic impacts of RIL on net present value are reported by Boltz (1999).

[17] In the RIL Block, the crew also recorded names, dbh, and coordinates for "next harvest trees" with dbh's from 35cm – 45cm because the existing inventory only included trees > 45cm.

Conventional logging creates large gaps in the forest canopy, severely damages residual trees and has negative impacts on forest soils.

while two technicians assessed and recorded damage. Severity of damage to bole and crown, cause of damage, and health status of each tree in the census were assessed using a modification of the method reported by Johns et al. (1996), and is shown in Table 1.

3.5.2 Ground area affected by heavy machines

RIL systems are designed to reduce the impact of heavy machinery on the forest floor. Reduced ground disturbance is expected to yield greater future forest productivity because less regeneration is destroyed during harvest operations and less mineral soil exposed.

The overall area of the RIL and CL blocks affected by roads, log decks and skid trails was measured. The same technician used a chain to measure the length and width of every road, skid trail and log deck in both harvest areas. Simultaneously, the relative direction was recorded to allow these areas to be added to the post-harvest map. In the office, surface area was estimated as (*length* x *width*). Although compaction was not measured, disturbance severity was estimated. Every 30 meters along all skid trails, an observation was made to evaluate whether mineral soil was exposed and if the litter layer or vegetation remained. The sampling unit was a single line across the width of the skid trail. Overall disturbance was the percentage of lines with exposed soil.

Table 1. Criteria used during post-harvest damage assessment.

Severity Class	Crown Damage	Bole Damage[18]	Cause of Damage	Health Class
0	No damage, complete crown	No damage	No damage	No damage
1	Minor damage, i.e. < 1/3 of crown damaged	Minor damage to < 1,500 cm^2 of bark	Felling	Clear signs of recovery
2	Moderate damage, i.e. > 1/3, but less than 2/3 of crown destroyed	Minor damage to > 1,500 cm^2 of bark	Skidding	No sign of recovery or death/decay
3	Severe damage, i.e. crown smashed	Moderate damage, i.e. deeper than bark, but < 1,500 cm^2 in area	Road building	Clear signs of death or decay (e.g. insect of fungal attack)
4	N/A	Severe damage to area > 1,500 cm^2, e.g. a major tear or broken branch	Log deck construction	N/A
5	N/A	Irreversible damage (clearly dead or dying), e.g. smashed bole	Natural causes (unrelated to harvest activities)	N/A

4. Results

4.1 Overview of timber harvests on RIL and CL sites

Pre-harvest inventories indicated that more trees were available for harvest on the CL block than the RIL block (Table 2). For the RIL block, some trees were "de-selected" by the timber marking crew due to defect, lean or other factors jeopardizing harvest. For the CL and RIL blocks, trees were also de-selected by the sawyer. As a consequence of the "hit and miss" search procedure used by conventional loggers, nearly half of the trees on the "potentially harvestable" inventory list were never found by the sawyer. In addition, the CL sawyer cut many trees that did not meet harvest criteria due to size or species restrictions.

The number of trees cut on the CL block (425 trees) was about 30% larger than the number cut on the RIL block (328 trees). On the CL block, about 4% of the trees felled were not found by the skidding team (16 trees) and about 3 % of the trees felled were not skidded because of a lack of merchantable wood in the bole (12 trees). About 15% of the trees cut on the CL block were *not on the harvest list and did not meet harvest criteria (62 trees). For the RIL operation, less* than 1% of the trees felled were not skidded (3 trees). The number of trees harvested (skidded to the log deck) on the CL block exceeded the number of trees harvested on the RIL block by about 21% (69 trees).

18 For classes 1 and 3 the technicians also recorded the approximate length and width of the damage.

Table 2. General harvest characteristics on the 1996 CL and RIL 100 ha blocks in Cauaxi.

Characteristic	**Conventional (CL)**	**Reduced-impact (RIL)**
Trees selected (by FFT) and/or viable for harvest from inventory list (i.e. trees meeting harvest criteria)	726	670
Trees rejected during tree marking because of defect (from list)	0	217
Trees marked for harvest after searching for defect (from list)	0	453
Trees on list rejected because of defect after testing by sawyer	15	126
Trees on list meeting harvest criteria not cut because not found by sawyer	347	0
Trees cut (on list and meeting harvest criteria)	363	327
Trees cut (*not* on list i.e. *not* meeting harvest criteria)	62	0
Trees with usable wood knocked over during felling and harvested (not on list)	0	4
Total trees cut	***425***	***331***
Trees not skidded because not found by skidding team	16	1
Trees not skidded because of lack of usable wood	12	2
Total trees skidded to log deck (i.e. harvested)	***397***	***328***

4.2 Ground area disturbed

The amount of ground area disturbed by the operation of heavy machinery on the CL block was nearly twice the ground area disturbed by RIL operations (Table 3).[19] Overall, heavy equipment disturbed about 10% of the ground area in the CL block versus about 5% of the ground area in the RIL block. Although this result was partially due to the higher harvesting intensity on the CL block, the ground area disturbed on a per tree harvested basis was about 60% greater on the CL relative to the RIL block. In addition, we note that 100% of the CL skid trails were cleared to mineral soil, whereas less than 10% of the RIL skid trails had mineral soil exposed.

It may be possible to utilize the same secondary roads, log decks and primary skid trails in the next harvest for RIL operations. Not only would this allow the landowner to amortize infrastructure investment over more than one harvest, it would also reduce long-term ecological

[19] This 2-to-1 ground disturbance ratio is similar to results reported by Hendrison (1990) comparing conventional and controlled logging in Suriname.

impact. Because it is unlikely that roads, log decks and skid trails will be used again in CL operations, cumulative financial and ecological impacts over several harvests are expected to be higher for CL operations.

Table 3. Ground area disturbed (m^2) per tree harvested by CL and RIL operations and total hectares disturbed for the entire 100 ha block.*

Activity	Conventional logging		Reduced-impact logging	
	m^2 / tree harvested	ha / 100 ha block	m^2 / tree harvested	ha / 100 ha block
Secondary roads	34	1.35	20	0.65
Log decks	26	1.05	19	0.63
Skid trails	193	7.66	120	3.90
Total	**253**	**10.05**	**159**	**5.18**

**In the CL operation, 397 trees were harvested; 328 trees were harvested in the RIL operation*

4.3 Harvesting waste

RIL activities were effective in reducing the amount of wood wasted relative to the CL operation (Table 4). Wood wasted in the CL (RIL) operation represented about 23.9% (7.6%) of the standard harvest volume. Clearly, RIL activities resulted in a large gain in timber utilization efficiency.

Table 4. Merchantable wood wasted in the forest and on the log decks by CL and RIL operations.

Source	CL waste (vol./ha)	RIL waste (vol./ha)
High stumps	0.28 m^3	0.10 m^3
Split logs	0.87 m^3	0.31 m^3
Bucking waste	1.97 m^3	0.85 m^3
Logs lost	0.96 m^3	0.06 m^3
Total forest	**4.08 m^3**	**1.32 m^3**
Log deck	1.97 m^3	0.60 m^3
Total	**6.05 m^3**	**1.92 m^3**

Most of the wood wasted in the forest was due to improper bucking of logs (CL = 1.97 m^3/ha vs. RIL = 0.85 m^3). On the CL block, the second most important source of wasted wood was logs not found by skidding operation (0.96 m^3/ha). On the RIL block, only 1 log, representing 0.06 m^3/ha, was not found by the skidding crew. Logs split due to improper felling accounted for 0.87 m^3/ha on the CL block and 0.31 m^3/ha on the RIL block. Cutting stumps too high wasted

0.28 m^3/ha on the CL block and 0.10 m^3/ha on the RIL block. Finally, wood left unutilized on the log deck amounted to 1.97 m^3/ha on the CL block and 0.60 m^3/ha on the RIL block.

Waste factors shown in equation (5) were computed using data in Table 5. For the CL (RIL) operation, $\forall$ = 0.034 (0.012), $\exists$ = 0.039 (0.002) and $*$ = 0.078 (0.024). The sum $\forall + \exists + *$ indicates the volume of wood wasted per unit recovered that incurred a direct cost. Entering these values into equation (6) resulted in a waste adjustment cost of \$0.40/m^3 for typical CL operations and \$0.09/m^3 for typical RIL operations.

Stumpage costs were computed to account for the difference in wasted wood volume between RIL and CL blocks (equations 7 through 9). Stumpage cost on the RIL block was estimated as \$7.61/ha ([\$193/ha]/[25.36 m^3/ha]). Using the estimated value) = 4.13 m^3/ha, stumpage cost on the CL block was estimated to be \$9.09/ha. The CL system increased effective stumpage price by \$1.48/m^3 due to poorer recovery of the volume potentially available.

4.4 Damage to next harvest trees

The RIL system reduced the number of fatally damaged trees in the residual stand by more than 50 percent (Table 5). For every 100 trees felled on the CL block (RIL block) , 38 trees (17 trees) in the residual stand that were commercial or potentially commercial, greater than 35 cm dbh and with good form, were fatally damaged. This fact suggests that economic and ecological benefits

Table 5. Potential future crop trees (commercial & potentially commercial species; form class 1 & 2) damaged per tree harvested by felling and other activities of the CL and RIL operations. (The total number of trees is shown in parentheses.)

Health class	Conventional Logging		Reduced Impact Logging	
	Felling Damage	Damage from other activities	Felling Damage	Damage from other activities
Recovering	0.14 (54)	0.11 (43)	0.24 (80)	0.17 (57)
No sign of change	0.16 (63)	0.05 (21)	0.18 (58)	0.05 (17)
Dying	**0.34 (136)**	**0.04 (16)**	**0.16 (52)**	**0.01 (2)**
Total Impacted	**0.64 (253)**	**0.20 (80)**	**0.58 (190)**	**0.23 (76)**

provided by the residual stand will be greater on the RIL block. As can be seen, felling is the most important cause of tree mortality.[20] Felling accounted for 98 % of human-induced damages on the CL block and 96% of human-induced damage on the RIL block.

[20] Natural causes accounted for an additional 61 trees on the CL block and 50 trees on the LIL block that were dead or dying.

4.5 Pre-harvest planning, harvest planning and infrastructure cost

For the standard RIL block, it was estimated that pre-harvest and harvest planning costs $1.34/m^3 (Table 6). Although planning reduced road and log deck construction costs relative to CL, total infrastructure costs were slightly higher in the RIL system due to skidtrail layout.[21] Overall, planning and infrastructure costs were about 2.6 times larger in the RIL operation relative to the CL operation. Recognition of the increment in fixed costs may hinder adoption of RIL systems.

Table 6. Pre-harvest, harvest planning and infrastructure costs per cubic meter.

Activity	Average cost of CL operations	Average cost of RIL operations*
	US$/m^3	US$/m^3
Pre-harvest Planning		
Block layout[a]	--	0.26
Inventory[b]	--	0.48
Vine cutting[b]	--	0.14
Data processing[c]	--	0.10
Mapmaking[c]	--	0.20
Harvest Planning		
Tree hunting (**)	0.14	--
Tree marking	--	0.13
Road planning[a]	--	0.02
Log deck planning[a]	--	0.01
Infrastructure		
Road construction[b]	0.28	0.16
Log deck construction[b]	0.29	0.16
Skidtrail layout	--	0.27
Total	**0.71**	**1.93**

* RIL costs marked with a, b, and c were compounded at 27.4% per annum to reflect the fact that these costs were incurred prior to harvest. Activities marked with 'a' were compounded for 8 months; 'b' were compounded for 7 months; and 'c' were compounded for 3 months. ** Tree hunting occurs at the time of harvest in CL operations.

4.6 Harvesting productivity and cost

Felling and bucking productivity were marginally lower for the typical RIL operation relative to the typical CL operation, presumably due to additional time taken to directionally fell trees and buck logs to maximize wood utilization on RIL sites (Table 7). However, skidding and log deck

[21] Skidtrails are not laid out in advance in CL operations.

productivity were about 40 percent higher for RIL due to increased efficiency in finding logs, optimally orienting skidding equipment, and reduced return time to the log deck. Overall, the typical RIL system reduced felling, bucking, skidding and log deck costs by $1.35/m^3 which more than compensated for incremental costs of pre-harvest, harvest planning and infrastructure activities ($1.20/m^3).

Table 7. Productivity and cost of harvesting operations

Activity	CL productivity (m^3/hr)	CL cost (US$/m^3)	RIL productivity (m^3/hr)	RIL cost (US$/m^3)
Felling & bucking	20.46	0.49	18.65	0.62
Skidding	22.39	1.99	31.66	1.24
Log deck operations	22.39	2.01	31.66	1.28
Total	**--**	**4.49**	**--**	**3.14**

4.7 Costs and returns from RIL versus CL operations

A comparison of the cost and revenue for typical, large scale RIL and CL operations in the Paragominas timbershed is shown in Table 8. Pre-harvest planning, harvest planning and infrastructure activities for the standard RIL operation increased "up-front" costs incurred before harvest by $1.20/m^3 over CL operations. This disparity provides an apparent disincentive to adopt RIL methods. However, efficiency gains due to planning typical RIL operations were large. Skidding and log deck productivity increased dramatically on the typical RIL operation and led to a 37% reduction in cost relative to CL ($4.00 - $2.52 = $1.48/m^3). Better recovery of potential merchantable volume on the typical RIL site reduced direct cost associated with waste by 78% ($0.31/m^3) and reduced stumpage cost by 16% ($1.48/m^3).

Overall, cost per cubic meter associated with a typical RIL system in this timbershed was estimated to be 12% less than the cost of a typical CL system, representing a cost savings of $1.84/m^3. Applying a value of $25.50/m^3 for gross revenue received on the log deck, the net profit margin (net revenue/gross revenue) for a typical RIL operation was estimated to be 45.7%. While this compares favorably with the net profit margin estimated for a typical CL operation (38.5%), such a margin for CL operations is impressive. To the degree that forest product firm are able to realize large profit margins, they may be averse to modifying harvesting operations.[22] Rather, it is logical to maximize the "throughput" of logs harvested to capture profits as quickly as possible.[23]

[22] Logging and sawmill companies in Par< generated a net profit margin of nearly 33% (Jenkins and Smith 1999).
[23] This logic is apparent in the piece rate payment system used for timber fellers in typical large-scale CL operations.

Table 8. Costs and returns of CL versus RIL operations.

Activity	**CL (US$/m³)**	**RIL (US$/m³)**	**Increase or (*Decrease*) RIL – CL**
Pre-harvest	0.00	1.18	1.18
Harvest Planning	0.14	0.16	0.00
Infrastructure	0.57	0.59	0.02
Felling & bucking	0.49	0.62	0.13
Skidding	1.99	1.24	(*0.75*)
Log deck operations	2.01	1.28	(*0.73*)
Waste adjustment	0.40	0.09	(*0.31*)
Stumpage cost[1]	9.09	7.61	(*1.48*)
Training[2]	--	0.21	0.21
Overhead/support	0.97	0.86	(*0.11*)
Total cost	**15.66**	**13.84**	**(*1.84*)**
Gross returns	25.50	25.50	0.00
Net revenues	**9.84**	**11.66**	**1.84**

[1] Stumpage costs are higher on typical CL operations because more wood is wasted and, therefore, per hectare price of harvesting rights is spread over fewer units of volume recovered.
[2] Costs were not computed for on-the-job-training (OJT) for CL operations, nor were increased equipment costs due to rough treatment.

5. Conclusions and Discussion

Our comparison of the financial costs and benefits of reduced-impact versus conventional logging showed that, for the initial harvest, the cost per cubic meter associated with a typical reduced impact logging system was less than the cost of a typical conventional logging system in the Paragominas timbershed. Gains in productivity and reductions in waste more than compensated for higher planning costs. In addition, we found that RIL substantially reduced damage to the residual stand and to the ground area disturbed by the harvesting operation. This will presumably lead to greater financial and ecological benefits in the future.

As a first step in understanding the conditions under which RIL can compete financially with CL systems, it is instructive to compare our results with the study reported by Barreto et al. (1998)

for another site within the Paragominas timbershed (Fazenda Sete). This comparison provides an indication whether or not forest heterogeneity may overwhelm any possibility of generalizing study results or identifying a “feasible financial set” of timbershed conditions that favor RIL systems. The following comparisons are made on nine factors: (1) volume extracted, (2) planning costs, (3) cost of roads and landings, (4) felling costs, (5) skidding productivity, (6) wood wasted, (7) total costs, (8) gross receipts and (9) net receipts. In general, we found that our results were consistent with, but more conservative than, Barreto et al., and confirmed that RIL can lead to higher profits in this timbershed.

First, initial stocking at Fazenda Sete was higher than initial stocking at Cauaxi. On the planned (unplanned) harvest block at Fazenda Sete 38.6m^3/ha (29.7m^3/ha) were recovered. The volume recovered on the planned Fazenda Sete block was about 52% larger than volume recovered on the standard block at Cauaxi (25.36m^3/ha). In general, an inverse relationship is expected between initial stocking and average cost. A higher stocking at Fazenda Sete suggested that average costs should have been lower there than at Cauaxi. This is what was found.

Second, average planning costs were lower on the standard RIL block at Cauaxi ($1.34/$m^3$) than on the planned block at Fazenda Sete ($1.87/$m^3$). This was due to lower block layout, vine cutting, data processing and mapmaking costs.

Third, average costs of roads and landings were higher on standard RIL and CL blocks at Cauaxi than at Fazenda Sete, presumably due to spreading costs over lower stocking at Cauaxi. Savings in road and landing costs due to planning at Cauaxi ($0.25/$m^3$ or 44% lower than CL) were greater than proportional savings at Fazenda Sete ($0.13/$m^3$ or 32% lower than CL).

Fourth, because felling and bucking costs were not separately recorded at Cauaxi, costs were not directly comparable with felling costs at Fazenda Sete. However, average felling and bucking costs for RIL (2 person team) were 27% higher ($0.13/$m^3$) than felling and bucking costs for CL (2 person team). This was presumably due to directional felling and more careful bucking on the RIL block. At Fazenda Sete, felling costs for planned logging (2 person team) were 1% higher than felling costs for unplanned logging (2 person team). The least cost at Fazenda Sete was for planned logging with a three person felling team.

Fifth, skidding productivity was somewhat higher at Fazenda Sete than at Cauaxi, again presumably due to the higher stocking. However, planning led to large increases in skidding productivity at both sites (41% gain relative to CL at Cauaxi and 27% gain relative to unplanned logging at Fazenda Sete). These results were consistent with large gains in skidding productivity reported by Hendrison (1990) for planned logging in Suriname. Gains in skidding productivity and, consequently, log deck productivity are major financial benefits of RIL.

Sixth, RIL led to large reductions in the volume of wood wasted at Cauaxi and Fazenda Sete. Total wood volume lost in the forest at Cauaxi was 4.08m^3/ha for CL (or 16% of standard volume) and 1.32m^3/ha for RIL (5% of standard volume). Logs left unutilized on the log decks at Cauaxi was also an important waste category for CL. At Fazenda Sete, unplanned logging resulted in 8.83m^3/ha wood wasted (26.4% of felled volume) and planned logging resulted in 0.40m^3/ha wood wasted (1% of felled volume). Because wasted wood incurs direct and indirect costs, reductions in wood wasted due to planning is a second major benefit of RIL.

Seventh, average total logging costs associated with RIL were lower than CL costs at both Cauaxi and Fazenda Sete. At Cauaxi, RIL reduced logging costs by $1.84/m^3 (12%) relative to CL. At Fazenda Sete, planned logging reduced logging costs by $2.12/m^3 (14%) relative to CL. Conventional logging costs were very similar at Cauaxi ($15.68/m^3), Fazenda Sete ($15.01/m^3) and as reported by Ferreira (1996) for the Paragominas timbershed ($15.45/m^3). RIL logging costs were somewhat higher at Cauaxi ($13.84/m^3) than at Fazenda Sete ($12.89/m^3) presumably due to the lower initial stocking at Cauaxi and the higher volume of wood wasted in RIL operations at Cauaxi.

Eighth, gross log receipts on the forest log deck were very similar at Cauaxi and Fazenda Sete. At Cauaxi gross receipts were $25.50/m^3 and at Fazenda Sete gross receipts were $27.21/m^3. This modest difference may be explained by differences in species mix recovered.

Finally, net receipts were higher for RIL relative to CL at Cauaxi and Fazenda Sete. At Cauaxi, net receipts from RIL were $1.84/m^3 higher (19% gain) and at Fazenda Sete, net receipts from planned logging were $3.68/m^3 higher (35% gain). Although gains from RIL were higher at Fazenda Sete, the results from Cauaxi confirm that RIL methods can increase logging profits in this timbershed.

By implication, lower average costs and higher average net revenues associated with RIL would tend to induce adoption and diffusion of RIL technology, *ceteris paribus*. However, several constraints to adoption deserve mention. First, much of the financial benefit of RIL was caused by the impact of reduced wood waste on costs. However, because CL operators have not typically adopted "full cost" accounting systems, direct and indirect costs associated with wood waste are not generally accounted for. Until "full cost" accounting systems are adopted, a major financial benefit of RIL systems will go unrecognized.

Second, "up-front" costs associated with activities that occur before timber harvesting begins were much higher for RIL operations. This may create the perception that RIL is more expensive than CL.

Third, adjustment costs related to optimal machine replacement and worker training may be nonzero. For example, logger training occurs during the harvest season. The opportunity cost (in terms of labor foregone) to the logging firm of training forest workers in RIL methods may be a significant impediment to making investments in "human capital". Likewise, RIL trained forest workers may have an incentive to seek more desirable employment elsewhere in the forest products industry after training.

Fourth, we found that estimated net profit margins for typical CL operations were impressive. This situation may provide limited financial incentive for seeking cost reductions.

Fifth, indirect costs associated with wasted wood were accounted for in this study by adjusting stumpage costs. We anticipate that standing timber will become increasingly scarce in this timbershed in the future. However, timber price appreciation may not keep pace with physical scarcity due to the absence of a timber price reporting system. Development of a price reporting system, as was implemented in the U.S. South, may induce full accounting for stumpage related costs and encourage investment in forest conservation.

Sixth, CL may provide greater financial returns than RIL if forestry codes and regulations designed to assure forest sustainability are violated. In the Brazilian Amazon, there has been a significant increase in the application of environmental regulations. The risk of fines or other penalties may offset any short run advantage to illegal logging and provide an incentive to loggers to adopt RIL methods.

We close by noting that the current demand for formal training in RIL methods by both large landowners and the Brazilian Federal Environmental Institute (IBAMA) suggests that further research and operational testing are needed to evaluate how variations in forest type, input and output markets and size of logging operation affect optimal design and performance of RIL systems. The identification of other timbersheds and tropical forest regions where economic self interest can help mitigate the loss of ecological services in forests subject to logging pressure will help sustainable tropical forest management become a reality.

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APPENDICES
Appendix 1: Summary of Average Cost by Activity

ACTIVITY	COST (US$/m^3) CL	COST (US$/m^3) RIL	COMPOUNDED COST (US$/m^3) RIL
Pre-Harvest			
Block layout	0.00	0.22	0.26
Inventory[1]	0.00	0.42	0.48
Vine cutting	0.00	0.12	0.14
Data processing	0.00	0.09	0.10
Mapmaking	0.00	0.19	0.20
Sub-total	**0.00**	**1.04**	**1.18**
Harvest Planning			
Tree hunting[2]	0.14	0.00	0.00
Tree marking	0.00	0.13	0.13
Road planning	0.00	0.02	0.02
Log deck planning	0.00	0.01	0.01
Sub-total	**0.14**	**0.16**	**0.16**
Infrastructure			
Road construction	0.28	0.14	0.16
Log deck construction	0.29	0.14	0.16
Skid trail layout	0.00	0.27	0.27
Sub-total	**0.57**	**0.55**	**0.59**
Harvest			
Felling & bucking	0.49	0.62	0.62
Skidding	1.99	1.24	1.24
Log deck operations	2.01	1.28	1.28
Sub-total	**4.49**	**3.12**	**3.12**
Support, Logistics & Supervision[3]	0.41	0.32	0.32
Activity sub-total	*5.61*	*5.19*	*5.39*
Overhead (10% of sub-total)[4]	**0.56**	**0.52**	**0.54**
Sub-total: activities + overhead	*6.17*	*5.73*	*5.93*
Stumpage	**9.09**	**7.61**	**7.61**
Waste Adjustment	**0.40**	**0.09**	**0.09**
Training		**0.21**	**0.21**
Total Cost	**15.66**	**13.64**	**13.84**

[1] Based on cost and productivity calculations for a 100% inventory of all trees (potentially commercial and commercial species) with diameter (dbh) > 35 cm.

[2] Cost of a "Mateiro" who "cruises" the stand for crop trees.

[3] For both RIL and CL operations, these costs include the field camp, generator, pickup truck, cook, and field supervisor. For RIL, the cost also includes a driver for the support vehicle (pickup truck). In CL operations, the supervisor typically drives this vehicle.

[4] Overhead refers to administrative support (office, phone, fax, computers, etc.).

Appendix 2: Hourly Costs by Activity for RIL & CL Practices

ACTIVITY	RIL Cost (US$/hr)	CL Cost (US$/hr)
Pre-Harvest		
Block layout & Line cutting	6.72	
Inventory	14.64	
Vine cutting	4.08	
Data processing	14.98	
Mapmaking	10.71	
Harvest Planning		
Tree hunting		2.81
Tree marking	9.06	
Road planning	8.85	
Log deck planning	8.87	
Infrastructure		
Road construction	45.39	40.53
Log deck construction	45.39	40.53
Skid trail layout	9.15	
Harvest		
Felling & bucking	11.55	10.01
Skidding	39.19	44.60
Log deck operations	40.45	44.98

Notes:

Block layout and line cutting: Labor = $6.54 (1 *Qualified Helper* and 2 *Helpers*). Materials = $0.18 (includes machetes, compass, 25 m measuring tape, waterproof marker, uniforms, hard hats, boots, safety vest, first aid kit, and canteens; see Materials Worksheet for details).

Inventory: Labor = $12.90 (1 *Technician II*, 1 *Identifier*, and 3 *Helper*s). Materials = $1.74 (includes items listed in note 1 plus 5m diameter tape + refills, clipboard, waterproof paper, mechanical pencils with refills, plastic tags, hammer, nails, and Dymo with daisy wheel for numbering tags).

Vine cutting: Labor = $3.98 (2 *Helper*s). Materials = $0.10 (includes hard hats, uniforms, safety vests, machetes, and boots).

Data processing: Labor = $14.98 (1 *Supervisor* and 2 *Technician II*s) constitutes total cost .

Mapmaking: Labor = $10.71 (1 *Supervisor* and 1 *Technician II*) constitutes total cost.

Tree hunting: Labor = $2.66 (i.e. total cost of 1 '*Mateiro*'). Materials = $0.15 (includes hard hat, boots, machete, and canteen).

Tree marking, road planning and log deck planning: Labor for Tree Marking, Road Planning, and Log Deck Planning = $8.82 each (1 *Technician II*, 1 *Qualified Helper* and 1 *Helper*). Since the same team conducts all three activities, the cost for most of the materials has been divided equally among the three activities. Materials = $0.24 for Tree Marking (includes safety materials + paint, paint gun, and adapter); $0.03 for Road Planning (includes safety materials + flagging); and $0.05 for Log Deck Planning (includes safety materials + flagging and 25 m survey tape).

Road and log deck construction*:* *RIL COSTS:* Labor for Road and Log Deck Construction = $11.28 each (1 *Operator 1* for CAT D6, 1 *Qualified Helper* and 2 *Helpers*). This same team conducts both activities. Consequently, the materials cost have been divided equally between the two activities. Materials = $0.06 each (includes hard hats, uniforms, boots, safety vest, first aid kit, machetes, safety glasses, emergency horn, canteens and whistle). Equipment = $34.05 (includes the hourly operating cost for the CAT Crawler Tractor – Model D6 Logger; see cost and depreciation schedule for details).

CL COSTS: Labor for Road and Log Deck Construction = $6.46 (1 *Operator 1* and 1 *Helper*). This team conducts both activities. Thus, the cost of materials has been divided equally between the two activities. Materials = $0.02. Equipment = $34.05, which is the same as RIL. Equipment costs are equal because the hourly cost of the CAT D6 is the same as in RIL.

Skid trail layout: Labor = $8.82 (1 *Technician II*, 1 *Qualified Helper* and 1 *Helper*). Materials = $0.33 (includes safety materials, flagging, mm paper, clipboard and pencil).

Felling and bucking: *RIL COSTS:* Labor = $8.20 (1 *Sawyer* and 1 *Helper* plus half the cost for 1 *Technician II* who supervises 2 felling crews as well as other activities. Equipment = $2.80 (i.e. the hourly operating cost of a Stihl AV 51 chainsaw with a 'rolling blade'; see cost and depreciation schedules). Materials = $0.55 (includes items listed in note 6 plus *Sawyer* safety materials, wedges, and fuel and maintenance materials for the chainsaw (see Materials Worksheet for details).

CL COSTS: Labor = $5.79 (1 *Sawyer* and 1 *Helper*). Equipment = $3.76 (i.e. hourly operating cost of a Stihl AV 51 chainsaw with a 'dry blade'). Materials = $0.46 (includes items required by law; see Materials Worksheet for details).

Skidding: *RIL COSTS:* Labor = $6.73 (1 *Operator 1* and 1 *Helper*). Equipment = $32.31 (includes the hourly operating cost of a CAT Skidder 525; see cost and depreciation schedule). Materials = $0.15 (includes choker tools).

CL COSTS: Labor = $10.53 (1 *Operator 1*, 1 *Sawyer*, and 1 *Helper*). In typical CL operations a *Sawyer* accompanies the CAT D6 Operator. Equipment = $34.05 (includes hourly operating cost of a CAT D6 Logger). Materials = $0.02.

Log deck operations: *RIL COSTS:* Labor = $9.29 (1 *Operator 1*, 1 *Qualified Helper* and 1 *Helper*). Equipment = $30.87 (includes the hourly operating cost of 1 CAT Loader – 938F and 1 Stihl AV 51 chainsaw with a rolling blade; see cost and depreciation schedule). Materials = $0.29.

CL COSTS: Labor = $12.82 (1 *Operator 1*, 1 *Sawyer*, 1 *Qualified Helper* and 1 *Helper*). Equipment = $31.83 (includes 1 CAT Loader – 938F and 1 Stilh AV51chainsaw with a dry blade; see cost and depreciation schedule). Materials = $0.33.

Appendix 3: Productivity

ACTIVITY	RIL PRODUCTIVITY	CL PRODUCTIVITY
Pre-Harvest	**ha/hr**	**ha/hr**
Block layout & Line cutting	1.19	
Inventory	1.36	
Vine cutting	1.36	
Data processing	6.25	
Mapmaking	2.26	
Harvest Planning	**ha/hr**	**m^3/hr**
Tree hunting		20.46
Tree marking	2.81	
Road planning	15.66	
Log deck planning	26.93	
Infrastructure	**ha/hr**	**ha/hr**
Road construction	12.5	5.70
Log deck construction	12.5	5.58
Skid trail layout	1.34	
Harvest	**m^3/hr**	**m^3/hr**
Felling & bucking	18.65	20.46
Skidding	31.66	22.39
Log deck operations	31.66	22.39

Notes:

Work hours: As a result of planning, inventory and road building the prior year, RIL operations can run for 8 months/year, whereas CL operations run for only 7 months / year. However, in both CL and RIL operations, each month has 22 workdays. The number of effective work hours/day is 7 for all pre-harvest and planning activities, 6.15 for felling, and 8 for all activities depending on heavy machines (i.e. road and log deck construction, skidding, and log deck operations).

Block layout and line cutting: 22,000 linear m serve each 100 ha block (inventory transects at 50 m intervals). Every 4th perimeter line is shared with the adjacent block. To calculate productivity, we divided 100 ha / 22,000 m; then we multiplied the result by 262.17 m / hr (the average productivity recorded from Cauaxi blocks 2, 3 & 5).

Inventory: Productivity is area inventoried per hour (ha/hr) obtained by adjusting the average productivity from 3 blocks in which FFT inventoried *all trees* w/ DBH ≥ 35cm to include only commercial and potentially commercial species.

Vine cutting: Vine cutting productivity is identical to inventory productivity because both activities occur together.

Data processing: Productivity based on an inventory of 3,800 commercial and potentially commercial trees (~ 190 trees per 5 ha inventory line). On average, one person can process data for 975 trees per day. Two people working at this rate would process 50 ha/day. 50 ha/day / 8 hrs/day = 6.25 ha/hr.

Mapmaking: We interpolated FFT productivity data for maps with 6,300 trees to estimate productivity for making a map with 3,800 trees. We first obtained an average productivity for the 3 kinds of maps (base map on mm paper, base map on vegetable paper, and harvest map on vegetable paper). We then determined the combined average productivity. Next we multiplied that average by 6,300/3,800.

Tree hunting: Since the Mateiro's productivity is limited by that of the felling crew, we assumed that the productivity for tree hunting would equal that for felling.

Tree marking: Average productivity from 9 FFT blocks.

Road planning: We used an average road planning productivity of 250.62 m/hr from 6 FFT blocks. We then divided the total linear m of roads needed to serve 100 ha (1,600m) by this average productivity (250.62 m/hr). The result (6.384 hrs) is the time needed to plan roads for 100 ha. We then divided 100 ha / 6.384 hrs to obtain the result above.

Log deck planning: For the RIL block in Cauaxi, 10 log decks totaling 5,000m^2 (each patio measures 20 m * 25 m) served 100 ha. Thus, we divided 100 ha / 5,000 m^2, then multiplied the result by the average productivity (from 3 blocks) which was 1,346.28m^2 / hr.

Road construction: For both RIL and CL we divided the linear m of roads built to serve 100 ha by the average linear m of road each operation can clear in an hour. For RIL this is: 100 ha / 1,600 m * 200 m/hr. 200m/hr is the average of 6 FFT blocks. For CL this is 100 ha / 2,139 m * 121.88 m/hr. 2,139 m is the distance measured at Cauaxi Block 1. 121.88 m/hr is the average from FFT survey. Both CL and RIL operations used a CAT Crawler Tractor (D6 Logger) to open roads.

Log deck construction: For both RIL and CL, we divided 100 ha by the area of log decks serving that 100 ha and then multiplied the result by the average area each operation could clear in 1 hour. RIL = 100 ha / 5,000 m^2 * 625 m^2/hr. See note 10 for area. 625 m^2/hr is average for 54 log decks. CL = 100 ha / 10,470 m^2 * 584 m^2/hr. Area is from total log deck area measured after harvest in block 1 at Cauaxi. 584 m^2/hr is average from 7 interviews (FFT survey). Both CL and RIL operations used a CAT Crawler Tractor (D6 Logger) to open log decks.

Skid trail layout: Average of 8 FFT blocks including Cauaxi 2, 3, & 4; AMACOL block 2; and all blocks in Marcelandia & Claudia.

Felling and bucking: RIL productivity is average from normal workdays on Cauaxi blocks 4 (13 days) & 6 (6 days) calculated as follows: [no. trees cut / hr in a particular block * average volume of trees in that block * no. of data points for that block] / total no. of data points.

CL productivity is average from FFT Survey and P. Barreto (unpubl. data). Both CL and RIL sawyers used a Stihl AV 51 chainsaw.

Skidding: RIL productivity is average from normal workdays on Cauaxi blocks 3, 4 & 6 calculated as follows: [no. trees skidded / hr in a particular block * average volume of trees in that block * no. of data points for that block] / total no. of data points. The RIL operation used a CAT Skidder (525) with a grapple and winch.

CL productivity is average from FFT Survey, P. Barreto (unpubl. data), and IMAZON 1992 data. The CL operation used a CAT Crawler Tractor (D6 Logger) with a winch but no fairlead.

Log deck operations: In both CL and RIL, since the rate of log deck operations (sorting, measuring, and loading) is limited by skidding productivity, we equated the productivity for both activities. Both CL and RIL operations used a CAT Loader (938F).

Appendix 4a: RIL Cost Calculation

ACTIVITY	Cost (US$/hr)[1]	Productivity[2] (ha/hr)	(m³/hr)	Cost (US$/ha)[3]	Cost (US$/m³)[4]
Pre-Harvest					
Block layout	6.72	1.19		5.64	0.22
Inventory	14.64	1.36		10.76	0.42
Vine cutting	4.08	1.36		3.00	0.12
Data processing	14.98	6.25		2.40	0.09
Mapmaking	10.71	2.26		4.74	0.19
Harvest Planning					
Tree hunting					
Tree marking	9.06	2.81		3.22	0.13
Road planning	8.85	15.66		0.57	0.02
Log deck planning	8.87	26.93		0.33	0.01
Skid trail layout	9.15	1.34		6.83	0.27
Infrastructure					
Road construction	45.39	12.50		3.63	0.14
Log deck construction	45.39	12.50		3.63	0.14
Harvest					
Felling & bucking	11.55		18.65		0.62
Skidding	39.19		31.66		1.24
Log deck operations	40.45		31.66		1.28
Support					0.32
Activity sub-total					5.21
Overhead (10% of sub-total)					0.52
Sub-total					**5.73**

NOTES

1. See Appendix 2 for details
2. See Appendix 3 for details
3. Obtained by dividing Cost ($/hr) by Productivity (ha/hr)
4. For activities in which Productivity is computed in ha/hr terms (pre-harvest and planning), this value was obtained by dividing Cost ($/ha) by the average volume harvested from a standard harvest block (25.36 m^3/ha). For activities in which productivity exists in m^3/hr (harvest), this value was obtained by dividing Hourly Cost ($/hr) by Productivity ($m^3$/hr).

Appendix 4b: CL Cost Calculation

ACTIVITY	Cost (US$/hr)[1]	Productivity[2] (ha/hr)	(m³/hr)	Cost (US$/ha)[3]	Cost (US$/m³)[4]
Pre-Harvest					
Block layout					
Line cutting					
Inventory					
Vine cutting					
Data processing					
Mapmaking					
Harvest Planning					
Tree hunting	2.81		20.46		0.14
Tree marking					
Road planning					
Log deck planning					
Infrastructure					
Log deck construction	40.53	5.58		7.27	0.29
Road construction	40.53	5.70		7.11	0.28
Skid trail layout					
Harvest					
Felling & bucking	10.01		20.46		0.49
Skidding	44.60		22.39		1.99
Log deck operations	44.98		22.39		2.01
Support					0.41
Sub-total					5.61
Overhead (10% of sub-total)					0.57
Total					**6.18**

NOTES

1. See Appendix 2 for details
2. See Appendix 3 for details
3. Obtained by dividing Cost ($/hr) by Productivity (ha/hr)
4. For activities in which productivity exists in ha/hr terms (road & log deck construction), this value was obtained by dividing Cost ($/ha) by the average volume harvested per hectare on a standard harvest block (25.36 m^3/ha). For all other activities, this value was obtained by dividing Hourly Cost ($/hr) by Productivity ($m^3$/hr).

Appendix 5: Calculation of Hourly Costs Based on Monthly Base Salaries (in 1996 US$)

Job Title (CL / RIL)1	Status[2]	No. of Minimum Wages[3]	Base Salary[4]	Legal Burden[5]	Food Cost[6]	Additional Costs (CL)[7]	Additional Costs (RIL)7	Total Monthly Cost (CL)[8]	Total Monthly Cost (RIL)8	Daily Cost (CL)[9]	Daily Cost (RIL)[9]	Hourly Cost (CL)[10]	Hourly Cost (RIL)[10]
Encarregado / Supervisor	P	6.5	734.78	346.52	52.17	-	-	1,133.48	1,133.48	51.52	51.52	6.44	6.44
Leadman / Technician II	P	4.2	474.78	223.91	52.17	-	-	750.86	750.86	34.13	34.13	4.27	4.27
Operator I	P	4.7	531.30	250.56	52.17	-	-	834.04	834.04	37.91	37.91	4.74	4.74
Operator II (Driver)	P	3.0	339.13	159.93	52.17	-	-	-	551.24	-	25.06	-	3.13
Sawyer	P	3.0	339.13	159.93	52.17	-	-	551.24	551.24	25.06	25.06	4.07	4.07
Cook	T	2.0	226.09	87.79	52.17	89.76	84.16	403.63	450.21	18.35	20.46	2.29	2.56
Qualified Helper	T	2.0	226.09	87.79	52.17	89.76	84.16	403.63	450.21	18.35	20.46	2.29	2.56
Helper	T	1.5	169.57	65.84	52.17	67.31	63.11	302.72	350.69	13.76	15.94	1.72	1.99
Matéiro / Identifier	P	2.5	282.61	133.28	52.17	-	-	468.06	468.06	21.28	21.28	2.66	2.66

NOTES:

1. Jobs listed are those that typically exist in the forestry sector in the Brazilian Amazon. In most cases, job titles between CL and RIL are identical. If they are not, the CL title is listed first. In RIL operations, a Technician I can usually fulfill the tasks of an "Encarregado". The "Mateiro" (i.e. "woodsman") identifies commercial trees for harvest, but does not tag or mark them. Although this table standardizes monthly, daily and hourly labor costs for CL and RIL operations, we assume that RIL crews work a total of 8 months in the field during a typical harvest year, whereas CL crews work only 7 months in the field. The extra month in RIL operations is gained as a result of inventory, road building, and planning in the previous year. CL operations would not typically use a driver for the 4WD support vehicle; thus, the cost of the Operator II is only included in the RIL costs.
2. Jobs titles with a 'P' status are considered permanent employees. Those with a 'T' status are temporary employees. Costs for temporary vs. permanent employees are calculated differently as indicated below.
3. Most salaries in Brazil are based on a multiple of the federally mandated minimum wage, which was US$113.04 in 1996.
4. The Base Salary is the monthly salary (i.e. minimum wage times number of wages) for each employee. This is what the employee actually receives. Other columns refer to taxes and other costs.
5. Legal Burden consists of federal and state taxes as well as social security and health insurance. Legal Burden is 47.16% of the Base Salary for Permanent workers and consists of: FGTS (8%), PIS (1%), INSS (23%), Holiday Bonus (2.78%), SSS (4.05%), and 13th month pay (i.e. annual bonus) distributed over 12 months (i.e. 8.33%). Legal Burden is only 38.83% of the Base Salary for Temporary workers because their proportional 13th month pay is included in the Additional Costs. The reason for this is that the legal proportion of Temporary workers' 13th month pay is distributed only over the number of months that they actually work (7 months in CL operations and 8 months in RIL operations). See explanatory table below.

6. Food costs were calculated based on the assumptions that (1) in a typical "harvest" month, all workers will be in the forest, and hence need food, for 24 days (i.e. 22 work days plus 2 Sundays during which workers remain in the field and eat even though they do not work); and (2) daily food costs average US$2.17.

7. By Brazilian law, employers incur additional costs when they fire employees. These costs are based on the number of months the employee worked. Employers in both CL and RIL operations would incur these costs when they dismiss Temporary employees. These costs differ for CL and RIL operations because they are spread over 8 months for RIL workers and 7 months for CL workers (see Note 1 above).

8. Monthly costs for both RIL and CL operations = Base Salary + Legal Burden + Food + Additional Costs.

9. Daily costs for both RIL and CL operations were calculated by dividing the monthly cost by 22 work days. We obtained 22 work days by assuming an average month has 30.5 days and then subtracting 8.5 days which is the average number of non-work days per month. We obtained 8.5 non-work days by assuming an average month has 1 sick day, 1 holiday, 4.2 Sundays, 2 non-working Saturdays, and 0.3 days for travel.

10. Hourly costs for both RIL and CL operations were calculated by dividing the daily cost by 8 hours (i.e. effective work hours/day) for all labor except sawyers. For both CL and RIL operations we divided the daily cost of sawyers by 6.15 hours, i.e. the average time sawyers typically work in the Amazon (based on IMAZON data).

Clarifying Examples

Example 1. Legal Burden Based on 1 Min. Wage (US$113)

Taxes & Benefits	%	P	T
FGTS	8%	9.04	9.04
PIS	1%	1.13	1.13
INSS	23%	26.00	26.00
Holiday Bonus	3%	3.14	3.14
SSS	4%	4.58	4.58
13th Month Bonus	8%	9.42	*
Total	47.16%	53.31	43.89

*13th month bonus for Temporary workers is included in additional costs (see note 5)

Example 2. Additional Costs for Temporary Workers in CL vs. RIL Operations

Cost Item	CL (7 mos)	RIL (8 mos)
30-day notice (1 Base Salary)	226.09	226.09
Legal Burden (38.83% of Base Sal)	87.79	87.79
40% of FGTS on Base Salary X Mos. Worked	50.64	57.88
Holiday Bonus* X Mos. Worked/12	131.88	150.72
13th Month Bonus* X Mos. Worked/12	131.88	150.72
Total	628.29	673.20
Additional Costs (Total/Mos Worked)	89.76	84.15

* Holiday Bonus & 13th Month Bonus are both based on one full Monthly Wage

Appendix 6a: Cost Calculation Worksheet for Materials Used in CL and RIL Operations by Activity

Activity	Item	Unit Price US$	Useful life (yrs)	Quantity Used RIL	Quantity Used CL	Hourly Cost/Harvest US$ RIL	Hourly Cost/Harvest US$ CL
Pre-Harvest Activities							
Block Layout	Safety Materials*					0.04	0.05
	Compass	74.78	3	2	0	0.04	0.00
	Survey Tape	59.13	2	2	1	0.05	0.03
	Waterproof Marker	5.22	1	8	0	0.04	0.00
	5l Jug	2.02	1	1	1	0.00	0.00
Sub-total						**0.18**	**0.08**
Inventory	Safety Materials					0.21	0.05
	Diameter tape refill	25.22	1	8	0	0.18	0.00
	5m diameter tape	30.00	3	1	1	0.01	0.01
	Clipboard	2.17	1	1	0	0.00	0.00
	Waterproof Paper	11.84	1	20	0	0.21	0.00
	Pencil Lead	0.87	1	8	0	0.01	0.00
	Machanical Pencil	1.74	1	8	1	0.01	0.01
	Plastic Tags	2.17	1	500	0	0.97	0.00
	Hammer	2.17	5	2	0	0.00	0.00
	Nails	4.35	1	16	0	0.06	0.00
	Dymo (Label maker)	175.65	5	2	0	0.06	0.00
	Daisy Wheel for Dymo	6.96	1	2	0	0.01	0.00
	5l Jug	2.02	1	1	1	0.00	0.00
Sub-total						**1.74**	**0.07**
Vine Cutting							
	Safety Materials					0.10	
Sub-total						**0.10**	**0.00**
Planning Activities							
2^o Road Planning	Safety Materials					0.03	
	Flagging	1.04	1	20	0	0.02	0.00
	5l Jug	2.02	1	1	0	0.00	0.00
Sub-total						**0.05**	**0.00**
2^o Road Construction	Safety Materials						
	Whistle	1.74	1	2	1	0.00	0.00
	5l Jug	2.02	1	1	1	0.00	0.00

Sub-total						**0.00**	**0.00**
Log Deck Planning	Safety Materials					0.03	0.00
	Flagging	1.04	1	30	0	0.03	0.00
	Survey Tape	59.13	2	1	0	0.03	0.00
	5l Jug	2.02	1	1	0	0.00	0.00
Sub-total						**0.08**	**0.00**
Log Deck Construction	Safety Materials					0.07	0.04
	Whistle	1.74	1	2	0	0.00	0.00
	5l Jug	2.02	1	1	1	0.00	0.00
Sub-total						**0.07**	**0.04**
Tree Marking	Safety Materials					0.05	0.00
	Paint Gun	34.20	2	2	0	0.03	0.00
	Paint Gun Adapter	6.17	0.5	2	0	0.02	0.00
	Tree-marking Paint	6.96	1	24	0	0.15	0.00
	5l Jug	2.02	1	1	0	0.00	0.00
Sub-total						**0.25**	**0.00**
<u>Harvest Activities</u>							
Felling	Safety Materials					0.43	0.43
	Wedge	8.04	5	5	0	0.01	0.00
	Sledgehammer	7.83	5	2	0	0.00	0.00
	Bag for Helper	10.43	1	4	0	0.04	0.00
	Fuel Jug	10.22	1	2	1	0.02	0.02
	Logger's Tape	42.17	2	2	0	0.04	0.00
	Hammer	2.17	5	2	1	0.00	0.00
	5l Jug	2.02	1	2	1	0.00	0.00
Sub-total						**0.55**	**0.46**
Skid Trail Planning	Safety Materials					0.05	
	Clipboard	2.17	1	1	0	0.00	0.00
	Polka dot flagging	1.49	1	60	0	0.07	0.00
	Striped flagging	1.04	1	60	0	0.05	0.00
	5l Jug	2.02	1	1	0	0.00	0.00
	mm paper (1/1000)	12.83	1	10	0	0.10	0.00
	mm paper (1/2000)	12.83	1	5	0	0.05	0.00
	Pencil Lead	0.87	1	4	0	0.00	0.00
	Mechanical Pencil	1.74	1	4	0	0.01	0.00
Sub-total						**0.33**	**0.00**
Skidding	Safety Materials					0.11	
	Clipboard	2.17	1	1	0	0.00	0.00
	Mechanical Pencil	1.74	1	4	0	0.01	0.00

	Pencil Lead	0.87	1	4	0	0.00	0.00
	5l Jug	2.02	1	1	1	0.00	0.00
	Gloves for Helper	4.35	1	3	1	0.01	0.01
	Whistle	1.74	1	2	0	0.00	0.00
	Fuel Jug	10.22	1	1	1	0.01	0.01
Sub-total						**0.15**	**0.02**
Log Deck Operations	Safety Materials					0.22	0.24
	Clipboard	2.17	1	1	1	0.00	0.00
	Mechanical Pencil	1.74	1	4	1	0.01	0.01
	Pencil Lead	1.74	1	4	1	0.01	0.01
	Metric Tape	59.48	1	1	1	0.05	0.05
	5l Jug	2.02	1	1	1	0.00	0.00
	Gloves	4.35	1	2	1	0.01	0.01
	Fuel Jug	10.22	1	1	1	0.01	0.01
	Whistle	1.74	1	2	0	0.00	0.00
Sub-total						**0.29**	**0.33**
Support & Logistics	Gas Pump	345.22	3	1	1	0.09	0.10
	Key	8.7	1	1	1	0.01	0.01
Sub-total						**0.16**	**0.18**
Total						**3.96**	**1.19**

***** By law, the following items are required for all forest workers who do not operate heavy machines or chainsaws: hard hat, uniform, safety vest, steel-toe boots, first-aid kit, & machete. In addition to these items, sawyers must use safety gloves and pants, earplugs, and a protective visor. Heavy machine operators must use earplugs and goggles.

Appendix 6b: Estimate of Hourly Operating Cost in US$ for CAT Skidder (525)

Depreciation Schedule & Value (based on 10,000 hours: 2,000 hrs/yr for 5 years)

Acquisition value (incl. Accessories):			$156,521.74
Cost of Tires			
Front	$7,826.09		
Rear	$7,826.09		
	Cost of Tires:		$15,652.17
Resale value (after 5 years):			$58,028.84
Liquid value to be depreciated:			**$82,840.72**

Fixed Costs of Ownership

Expenses:	
Depreciated Liquid Value divided by 10,000 hours:	$8.28
Using formula from CAT, the cost for Interest, Insurance and Tax is:	$7.04
Annual machine use in hours = 2000	
Interest (12%) + Insurance (1%) + Tax (2%) = 15%	
Liquid Value:	**$15.33**

Variable Costs of Operation

	Cons. / hr	Unit Price	Cost	
Diesel Fuel Consumption (liters)	15	$0.40	$6.00	$6.00
Lubricants & Other				
Engine	0.08	$2.83	$0.21	
Transmission	0.05	$2.83	$0.15	
Main Drivetrain	0.05	$2.83	$0.13	
Hydraulic System	0.03	$2.83	$0.10	
Grease			$0.09	
Filters			$0.22	
		Total	$0.89	$0.89
Tires (Price/useful life)				$7.83
Main Cable				$0.54
Choker Supplies				$0.22
Repairs & Maintenance				$7.30
Liquid Value:				**$22.78**
		Sub-total		$38.11
		Resale Credit		$5.80
		Total Hourly Cost		**$32.31**

Appendix 6c: Estimate of Hourly Operating Cost in US$ for CAT D6 SR Tractor

Depreciation Schedule & value (based on 10,000 hour: 2,000 hrs/yr for 5 years)

Acquisition Value (incl. Accessories)	$160,869.57
Resale Value (after 5 years)	$59,640.76
Liquid value to be depreciated:	$101,228.81

Fixed Costs of Ownership

Expenses	
Depreciated Liquid value Divided by 10,000 hours:	$10.12
Using formula from CAT, the cost for Interest, Insurance and Tax is:	$7.24
Annual machine use in hours = 2,000	
Interest (12%) + Insurance (1%) + Tax = 15%	
Liquid value:	$17.36

Variable Costs of Operation

	Cons./ hr	Unit Price	Cost	
Diesel Fuel Consumption (liters)	$16.00	$0.40	$6.40	$6.40
Lubricants and Other				
Engine	$0.05	$2.83	$0.15	
Transmission	$0.10	$2.83	$0.27	
Main Drivetrain	$0.04	$2.83	$0.11	
Hydraulic System	$0.03	$2.83	$0.07	
Grease			$0.09	
Filters			$0.30	
		Total	$0.99	$0.99
Track Parts				$4.85
Main Cable				$0.54
Choker Supplies				$0.22
Repairs & Maintenance				$8.70
Special Items				$0.96
Liquid value				$22.65
		Sub-total		**$40.01**
		Resale Credit		**$5.96**
		Total Cost		**$34.05**

Appendix 6d: Estimated Hourly Operating Costs in US$ for Loader (CAT 938F)

Depreciation Schedule & Value (based on 10,000 hour: 2,000 hrs/yr for 5 years)

Acquisition value (incl. Accessories):	$113,043.48
Cost of Tires	
Front	$7,826.09
Rear	$7,826.09
Total	$15,652.17
Resale Value (after 5 years)	$41,909.72
Liquid Value to be depreciated:	$55,481.58

Fixed Costs of Ownership

Expenses:	
Depreciated Liquid Value divided by 10,000 hours:	$5.55
Using Formula from CAT, the cost for Interest, Insurance and Tax is:	$5.09
Annual machine use in hours = 2000	
Interest (12%) + Insurance (1%) + Tax (2%) = 15%	
Liquid Value:	$10.64

Variable Costs of Operation

	Cons./ hr	Unit Price	Cost	
Diesel Fuel Consumption (liters)	15	$0.40	$6.00	$6.00
Lubricants & Other				
Engine	0.08	$2.83	$0.23	
Transmission		$2.83	$0.07	
Main Drivetrain		$2.83	$0.08	
Hydraulic System		$2.83	$0.07	
Grease			$0.17	
Filters			$0.30	
		Total	$0.93	$0.93
Tires (Price/useful life)				$5.22
Repairs & Maintenance				$8.52
Special Items				$0.96
Liquid Value:				$21.63
		Sub-total		**$32.26**
		Resale Credit		**$4.19**
		Total Cost		**$28.07**

Appendix 6e: Estimate of Hourly Operating Cost in US$ for Pickup Truck

Depreciation Schedule and Value (based on 6,000 hours for 5 years)

Acquisition Value (incl. Accessories)		$13,913.04
Cost of Tires		
Front	$286.96	
Rear	$286.96	
	Total:	$573.91
Resale value after 5 years:		$7,826.09
Liquid value:		$5,513.04

Fixed Costs of Ownership

Expenses:	
Depreciated Liquid Value divided by 6,000 hours:	$0.92
Using formula from CAT, the cost for Interest, Insurance and Tax is:	$1.04
Annual machine use in hours = 1200	
Interest (12%) + Insurance (1%) + Tax (2%) = 15%	
Liquid value:	$1.96

Variable Costs of Operation

	Cons./hr	Unit Price	Cost	
Diesel Fuel Consumption	$2.00	$0.67	$1.33	$1.33
Tires (Price/useful life)				$0.32
Repairs & Maintenance				$0.88
Liquid value:				$2.53
		Sub-total		**$4.49**
		Resale Credit		**$0.26**
		Total Cost		**$4.23**

Appendix 6f: Estimate of Hourly Operating Cost in US$ for Chainsaw (Stihl AV 051)

Depreciation Schedule & Value (based on 2,000 hours in 2 years)

Acquisition value (incl. Accessories)	$773.91
Resale Value (Depreciated 10% for 5 years)	$147.04
Liquid Value:	$626.87

Fixed Costs of Ownership

Expenses:	
Depreciated Liquid Value divided by 2,000 hours:	$0.31
Interest (12%)	$0.06
Insurance(1%)	$0.08
Capital Payment	$0.24
Liquid Value:	$0.68

Variable Costs of Operation

	Cons./hr (CL)	Cons./hr (RIL)	Unit Price	CL COST	RIL COST
Gasoline Consumption (liters)	1.3	0.78	$0.73	$0.95	$0.57
Lubricants & Other					
Chain	0.45	0.39	$1.74	$0.78	$0.68
Chains (CL: 20; RIL: 14)				$0.46	$0.28
Flat Files (CL: 12; RIL: 7)				$0.03	$0.02
Round Files (CL: 24; RIL: 14)				$0.08	$0.04
Blades (CL: 4 dry; RIL: 2 rolling)				$0.37	$0.18
Maintenance				$0.41	$0.36
Liquid value:				$3.09	$2.13

	CL(US$)	RIL(US$)
Sub-total	**$3.77**	**$2.81**
Resale Credit	**$0.01**	**$0.01**
Total Hourly Cost	**$3.76**	**$2.80**

Appendix 6g: Estimate of Hourly Operating Cost in US$ for Generator

Depreciation Schedule & Value (based on 7,500 hour for 5 years)

Acquisition Value (incl. Accessories)	$1,478.26
Resale Value (depreciated 18%/yr for 5 years)	$548.05
Liquid value	$930.21

Fixed Costs of Ownership

Expenses:	
Depreciated Liquid Value divided by 7,500 hours:	$0.12
Using formula from CAT, the cost for Interest, Insurance and Tax is:	$0.09
Annual machine use hours = 1500	
Interest (12%) + Insurance (1%) + Tax (2%) = 15%	
Liquid Value:	$0.21

Variable Costs of Operation

	Cons./hr	Unit Price	Cost	
Gasoline Consumption (liters)	$0.76	$0.67	$0.51	$0.51
Lubricants & Other				
Engine	$0.01	$281.74	$0.03	$0.03
Liquid Value:				$0.53
		Maintenance		**$0.05**
		Sub-total		**$0.80**
		Resale Credit		**$0.07**
		Total Hourly Cost		**$0.72**

Appendix 7: Calculation of Hourly Costs for Support, Logistics & Supervision

RIL

Camp		Total Cost		**Cost per Harvest**
		$594.61		$351.00
Generator		Hourly Cost	Hrs / Harvest[1]	**Cost per Harvest**
		$0.72	960	$692.87
Pickup Truck		Hourly Cost	Hrs / Harvest	**Cost per Harvest**
		$4.23	1200	$5,078.26
Salary - Cook		Additional Costs[2]	Months	**Cost per Harvest**
	$226.09	$224.12	8	$2,019.06
Salary - Driver		Additional Costs[2]	Months	**Cost per Harvest**
	$226.09	$224.12	8	$2,019.06
Salary - Supervisor		Additional Costs[2]	Months	**Cost per Harvest**
	$734.78	$398.70	8	$3,924.35
			Total =	**$14,084.60**
Total Volume (m^3) per 8 month Harvest[3]				**44,577**
Cost / m^3				**$0.32**

CONVENTIONAL

Camp		Total Cost		**Cost per Harvest**
		$594.61		$351.00
Generator		Hourly Cost	Hrs / Harvest[1]	**Cost per Harvest**
		$0.72	840	$606.26
Pickup Truck		Hourly Cost	Hrs / Harvest	**Cost per Harvest**
		$4.23	1200	$5,078.26
Salary - Cook		Additional Costs[2]	Months	**Cost per Harvest**
	$226.09	$229.72	7	$1,834.14
Salary - Supervisor		Additional Costs[2]	Months	**Cost per Harvest**
	$734.78	$398.70	7	$3,525.65
			Total =	**$11,395.31**
Total Volume (m^3) per 7 month Harvest[4]				**27,584**
Cost / m^3				**$0.41**

Notes:

1 We assumed 4 hrs/day * 30 days * 8 months (for RIL) and * 7 months (for CL).

2 The additional cost corresponds to the cost of food ($60/mo), legal burden, and other legal costs.

3 We multiplied the RIL skidding productivity of 31.66 m3/hr * 8 hours / day * 22 days * 8 months.

4 We multiplied the CL skidding productivity of 22.39 m^3/hr * 8 hours / day * 22 days * 7 months.

Appendix 8: Wood Waste Definitions and Methods

CATEGORY / PARAMETERS	PURPOSE	METHODS	COMMENTS
Trees on harvest list, not harvested	Ascertain % of merchantable volume not harvested	(1) determine vol. from database; (2) note reason not harvested (e.g. defect, seed tree, etc.)	Not included in waste calculations
Trees not found by loggers			
Trees purposely left			
Trees felled, not skidded			
Logs purposely left	Ascertain % of felled volume cut but with defect	Note reason not skidded (e.g. hollow, split, etc.)	Not included in waste calculations
Logs not found by skidder	Calculate volume of lost logs; included in total wood wasted	(1) Measure length of log & diameter in center of log. (2) Calculate volume (see formula A)	**Formula (A):** $V = 0.7854 * D^2 * H$; where D is diameter and H is height. Constant = ⑥ / 4.
Improper felling			
Cutting too high on stump (> 20cm above ground) - no buttresses	Calculate volume of wood wasted at the stump from improper felling practices	(1) Measure height (from ground) & diameter (two perpindicular measures) at undercut. (2) Determine usable height if cut made > 20 cm from ground and use that height to determine volume (see formula B)	
Cutting too high on stump (> 20cm above ground) - buttresses present		(1) Estimate largest round usable area in top of stump; (2) Take 2 perpindicular diameter measures of that area; and (3) Estimate or measure height of largest usable vertical portion of stump; (4) Calculate volume (see formula A)	
Poor felling technique	Ascertain if wood waste from split logs was due to operational error	Classify quality of cut: 1 = good or acceptable; 2 = at least 1 mistake; 3 = bad / unacceptable	Split trees were included in the waste calculation if the cut was classified as 'bad' or 'unacceptable'

Improper bucking

Logs w/ hollow sections	Calculate wood wasted from improper bucking of logs w/ hollow sections	(1) Take 2 perpindicular diameter measures of hollow. If hollow runs for entire length of log, measure diameter in the center of log only. (2) Measure length of entire log and of hollow section. (3) Measure diameter at midpoint of section starting 30 cm beyond end of hollow and also in the center of log. (4) Calculate volume (see formula B)	**Formula (B):** $V =$ ⑥ $/ 4 * [D_{log}-(D_{hb}+D_{ht})/2]^2 * H$; where D_{log} is the diameter at the midpoint of the usable portion of the log, D_{hb} is the average diameter at the base of the hollow, D_{ht} is the average diameter at the top end of the hollow, and H is the length of the usable portion of the log. Usable portions depended on criteria set by mills for each species.
Split logs	Calculate wood wasted from improper bucking of split logs and from improper felling	(1) Measure length of entire log. (2) Measure length of section starting 30 cm from end of "tight" split. (3) Measure diameter at midpoint of section starting 30 cm beyond end of split and also in the center of log. If log is split open down entire length, obtain diameter by measuring circumference of outer sides of both halves. (4) Calculate volume of usable portion (Formula A).	
Logs w/ buttresses	Calculate wood wasted from improper bucking of logs w/ buttresses	(1) Estimate & measure length of merchantable portion of log. (2) Measure diameter at midpoint of that length. If buttress begins where log was cut, take 2 perpindicular diameter measures at the cut end of the log. (3) Calculate volume (Formula A).	
Crown (Diam of stem > 30cm)	Calculate wood wasted from improper bucking of stems at the crown end	(1) Measure length of usable portion of stem and the diameter at its midpoint. (2) Calculate volume (Formula A).	Stems were considered unusable if the otherwise usable portion contained a branch w/ a diameter > 1/3 that of the stem.
Straight branches	Calculate wood wasted from improper bucking of usable branches	(1) Starting 30 cm above upper junction with main stem, measure length of longest usable section (see comment). (2) Measure diameter at midpoint of that section. (3) Calculate volume (Formula A).	Branches were considered as usable logs if they had a straight section > 3 m in length and > 30 cm in diameter.

CAUAXI BLOCK LAYOUT